

Ages, Distances, and the Initial Mass Functions of Stellar Clusters

J. R. Stauffer

Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA

R. D. Jeffries

Dept. of Physics, Keele University, Staffordshire, ST5 5BG, UK

E. L. Martín

Planetary Sciences Division, Caltech 105-21, Pasadena, CA 91125, USA

D. M. Terndrup

Dept. of Astronomy, Ohio State University, Columbus, OH 43210, USA

Abstract.

We provide a review of the current status of several topics on the ages, distances, and mass functions of open clusters, with a particular emphasis on illuminating the areas of uncertainty. Hipparcos has obtained parallaxes for nearby open clusters that have expected accuracies much better than has been previously achievable. By using the lithium depletion boundary method and isochrone fitting based on much improved new theoretical evolutionary models for low mass stars, it is arguable that we will soon have much better age scales for clusters and star-forming regions. With improved optical and near-IR cameras, we are just now beginning to extend the mass function of open clusters like the Pleiades into the regime below the hydrogen burning mass limit. Meanwhile, observations in star-forming regions are in principle capable of identifying objects down to of order 10 Jupiter masses.

1. Introduction

Rather than attempt to present an extremely abbreviated synopsis of all of the material covered by the panel, we give here a summary of a few of the presentations. For each main topic, I (JRS) will give a brief outline of the current paradigm and/or any well-known controversies. Individual presentations by members of the panel will follow, with the author of the contribution indicated by his initials at the end of the section title.

2. The Distances to Open Clusters

The classical open cluster distance scale is based on determining an astrometric distance to the Hyades, either via trigonometric parallax or convergent point or some similar analysis, and then using main-sequence fitting techniques to determine the distances of other clusters relative to the Hyades (thus requiring a small correction for the higher-than-solar metallicity of the Hyades). This method obviously requires an accurate knowledge of the cluster’s reddening and metallicity. It further requires good photometry over the color range where the cluster members lie on or near the ZAMS. Finally, large number statistics are useful in order that the single-star sequence be well-defined. The method assumes that the photometry for each cluster is accurately calibrated, that the metallicities are accurately known and the effects of metallicity correctly modeled, and that the corrections for interstellar extinction are accurately derived from the data.

For the nearer, richer open clusters, where photometry of large numbers of stars is available (often in several different photometric systems), the main sequence fitting distances are typically accurate to of order 5% in the distance (0.1 mag in the distance modulus) unless there is some significant error in the assumptions of the method. Using the available data, the commonly quoted distances to the Pleiades, Praesepe and Coma clusters from main sequence fitting are of order 130 pc, 158 pc, and 80 pc, respectively. Standard compilations of open cluster distances include Becker & Fenkart (1971), the Lynga catalog (Lynga 1987), and J.-C. Mermilliod’s on-line “Database for Stars in Open Clusters” (BDA) at <http://cdsweb.u-strasbg.fr/online/mermio.html>.

2.1. Comparison of Hipparcos Open Cluster Distances to MS Fitting Distances (DMT)

The high precision and large number of stars in the Hipparcos catalog made it possible for the first time to derive trigonometric distances to open clusters other than the Hyades (Robichon et al. 1999, van Leeuwen 1999), as well as an extremely precise (average) distance to the Hyades cluster itself ($m - M = 3.34 \pm 0.01$, Perryman et al. 1998). In several cases, particularly for the Pleiades and Coma clusters, the derived distances (118 pc and 90 pc, respectively for Pleiades and Coma) are significantly different from distances inferred from the technique of main-sequence fitting (MSF). If the Hipparcos parallax to the Pleiades were correct, then the main sequence of that cluster would be as much as 0.3 mag fainter than expected from stellar evolution theory.

Prompted by this discrepancy, Pinsonneault et al. (1998) re-examined the MSF distances to several open clusters with distances from Hipparcos, and in particular discussed how the luminosity of the main sequence depends on metallicity, helium abundance, and interstellar extinction. They concluded that none of these effects could produce the anomalous main sequence luminosity, and suggested that there could in some cases be systematic errors in the Hipparcos parallaxes on the order of 1 milliarcsecond (mas), about 10 times larger than the systematic errors in the parallaxes on a global scale.

Soderblom et al. (1998) examined the Hipparcos data base, selecting young main-sequence stars with parallax errors small enough that systematic errors at

the 1 mas level would be unimportant. If nature were able to produce subluminoous stars in the Pleiades, they reasoned, then there should be similar objects in the field. They were unable to find any, further suggesting that the Pleiades distance from Hipparcos was incorrect.

In the design of the Hipparcos experiment, it was known that a potential problem in determining the distances to open clusters is the possibility of correlated errors on small angular scales (e.g., Lindegren 1988). Furthermore, the typical density of stars in open clusters is significantly higher than the average across the sky. (Both these effects were included in the Hipparcos analysis of the cluster distances.) Narayanan & Gould (1999a) proposed a new method of examining the Hipparcos parallaxes in open clusters. Applying this to the Pleiades and Hyades (Narayanan & Gould 1999b), they showed that the Hipparcos parallaxes toward these open clusters are spatially correlated over angular scales of $2^\circ - 3^\circ$, with an amplitude of up to 2 mas. This correlation is stronger than expected based on the analysis of the Hipparcos catalog. Using a distance method based on the Hipparcos proper motions which should not be biased by these spatial correlations, Narayanan & Gould derived a distance to the Pleiades essentially equal to the main-sequence fitting distance but significantly different from that derived from the Hipparcos parallaxes. For the Hyades, by chance, the structure of the spatial correlations is such that the errors average out and the distance derived from the Hipparcos parallaxes agrees with that derived from main-sequence fitting.

The issue is not settled, however, because those most closely connected to the Hipparcos parallax measurements maintain that their distances are correct, and that there is an astrophysical explanation for the discrepant Pleiades and Coma cluster distances (see the talk in these proceedings by M. Grenon). Fortunately, there is reason to believe that a definitive resolution can now be expected from new observations because NASA has approved construction of a new astrometric mission called FAME, which should obtain parallaxes for many more stars and to significantly higher accuracy than Hipparcos – and provide the answers within the next decade based on an expected 2004 launch (see <http://aa.usno.navy.mil/fame/>).

3. Open Cluster Ages

The traditional open cluster age scale is based on fitting photometry of stars near the upper main sequence turnoff of a given cluster to theoretical evolutionary isochrones. The most widely referenced compendium of open cluster ages derived in that manner is probably Mermilliod (1981). In that paper, the ages of the Alpha Persei, Pleiades, and Hyades open clusters are listed as 51 Myr, 78 Myr, and 660 Myr, respectively. While other age indicators confirm the relative ordering of cluster ages given by Mermilliod, the absolute age scale has been a subject of some controversy. Most particularly, by adjusting the amount of “convective core overshoot” for stars near the MS turnoff, it is possible to derive cluster ages up to a factor of two older than those given in Mermilliod (1981): see, for example, Mazzei & Pigatto (1989) or Meynet et al. (1993).

An alternate way to estimate cluster ages is by determining the location of the pre-main sequence (PMS) turn-on point or the displacement of the PMS lo-

cus above the ZAMS. Because of fairly obvious realities, this method has mostly been applied to very young clusters. However, a few – perhaps foolhardy – authors have attempted to apply the method to “oldish” clusters like the Pleiades or Alpha Persei (Stauffer 1984; Stauffer et al. 1989). With the development of more accurate theoretical evolutionary models that extend to lower masses, it is now becoming more feasible to extend this type of age-dating to “oldish” open clusters, and two discussions of this topic are included below.

A new way to estimate the age of open clusters has recently been proposed by Basri, Marcy, & Graham (1996=BMG), Bildsten et al. (1997), Ushomirsky et al. (1998), Ventura et al. (1998) and others. The idea behind this method is that for stars near the substellar mass limit, the age at which stars become hot enough in their cores to burn lithium is a sensitive function of mass. Furthermore, it is argued that the physics required to predict the location of the “lithium depletion boundary” (LDB) as a function of age is very well understood and not subject to significant uncertainty (Bildsten et al. 1997). In the mass range of interest, stars are fully convective, and the core lithium abundance will be directly reflected in the surface lithium abundance – and the latter can be determined by use of the 6708Å Li I doublet.

BMG and Rebolo et al. (1996) were the first to successfully apply this test by detecting lithium in three substellar objects in the Pleiades. However, it was later determined (Basri & Martín 1999a) that the exact location of the lithium boundary (and hence the Pleiades age) was uncertain because the brightest of the three objects (PPL15) is a nearly equal mass binary. This problem was resolved by Stauffer, Schultz, & Kirkpatrick (1998=SSK), who obtained spectra of an additional 10 faint Pleiades members, five of which still retain their lithium and by Martín et al. (1998) who obtained spectra of an additional two Pleiades members, one of which had detected lithium. By providing measurements of a large number of stars near the lithium boundary, SSK claimed to determine the absolute magnitude of the lithium depletion boundary to an accuracy of about 0.1 mag, corresponding to an age uncertainty of about 8 Myr. The age derived for the Pleiades by SSK was 125 Myr.

More recently, Basri & Martín (1999b) and Stauffer et al. (1999) have determined an LDB age for the Alpha Persei cluster (based, respectively, on one and five members with detected lithium), and Barrado y Navascués, Stauffer & Patten (1999) have derived an LDB age for the IC2391 open cluster. The ages for all three clusters derived in this manner are systematically older (by of order 50%) than the ages quoted in Mermilliod (1981). If these LDB ages are as accurate and precise as believed, it should be possible to define a new open cluster age scale to replace Mermilliod (1981). Two of the panelists however urge caution at this point.

3.1. Limitations of the Lithium Depletion Boundary Method (RDJ)

Whilst the Lithium Depletion Boundary Method is potentially a very precise way of determining the age of a cluster, it is worth considering in some detail to what extent the age error budget is influenced by various sources of uncertainty. These can be placed into two categories; random and systematic.

My baseline assumption is that the age is found by locating the LDB in a colour-magnitude diagram (CMD), using the colour of the LDB and an empiri-

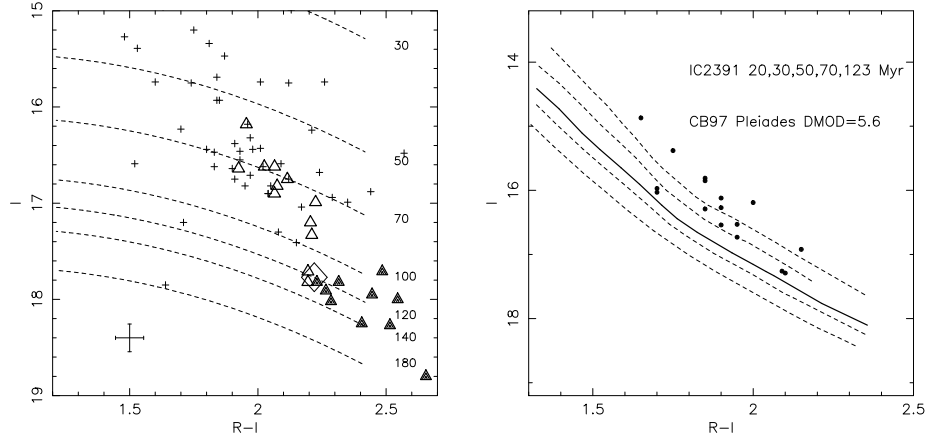


Figure 1. (a) CMD for the Pleiades showing Li detections (filled triangles), non-detections (open triangles) and members without Li measurements (crosses). The diamond indicates the assumed location of the LDB and its error. The error bar indicates the effects of other random errors (distance modulus, photometric calibration etc.). Dashed lines are isochrones of 99% Li depletion from Chabrier & Baraffe (1997), labelled in Myr. (b) A CMD for IC 2391. Isochrones are plotted for a number of ages including the LDB age (thick line). Isochrones are derived from Chabrier & Baraffe models, with an $R - I - T_{\text{eff}}$ relation calibrated on a Pleiades LDB isochrone of 123 Myr.

cal bolometric correction (BC) to find L_{bol} at the LDB and then using a model for Li depletion in cool stars to translate this into an age (see Fig. 1a). Random errors can be ascribed to uncertain placement of the LDB in the CMD, uncertain photometric calibrations and uncertainties in the distance and reddening of the cluster in question. Systematics arise from the chosen BC-colour relation, whether one assumes the LDB defines the point at which say 90% or 99% of Li has been depleted and the choice of evolutionary model which defines the L_{bol} -age relation at the LDB. The first two of these systematics will alter the ages of all clusters in qualitatively the same way, whereas the latter systematic may cause individual clusters to be older or younger, as the L_{bol} -age relations cross for differing evolution models. There may also be additional systematics due to common assumptions made by *all* the current generation of models.

I have investigated these uncertainties, focussing on clusters with an LDB defined in the I vs $R - I$ CMD, and using the theoretical models of Burrows et al. (1997), Chabrier & Baraffe (1997) and D’Antona & Mazzitelli (1997). Note that model colours and magnitudes from the former two sets of models have not been used as their uncertainties are unquantified. I find that for clusters with data quality similar to that available for the Pleiades, random errors in the age rise from $\pm 9\%$ at ~ 25 Myr, to $\pm 16\%$ at 200 Myr. These errors are dominated by uncertain placement of the LDB in the CMD (± 0.15 mag in I and ± 0.05 in $R - I$) along with distance modulus errors and uncertainties in the I photometric calibration (both around ± 0.1 mag). Obtaining Li data for more points around the LDB, distinguishing binaries from single stars and

tightening up the photometric calibration could reduce these errors considerably. The systematic errors are more constant, ranging between 7% and 11% over a similar age range. The systematics are due mainly to the choice of model and whether there is any age dependence in the BC-colour relation. The influence of whether Li is depleted by 90% or 99% at the LDB (say for Li 6708Å EWs $< 0.3\text{\AA}$) only alters ages by $\pm 3\%$.

In Table 1, I present the results of my analysis for the Pleiades, Alpha Per and IC 2391 clusters using Li spectra, I and $R - I$ data from the literature and averaging over the three evolution models. These ages are similar to those previously estimated (Stauffer et al. 1998, 1999; Barrado y Navascués et al. 1999), but the estimated errors are larger by a more than a factor of two. This does not alter the conclusion that LDB ages are older than turn-off ages with no core overshoot, but certainly obscures whether core overshoot might be mass dependent (see §3.2).

I also have evidence that there may be additional systematics in the LDB method that are not adequately reflected by simply choosing a variety of models. If I assume the Pleiades age is given by its LDB age for a given set of evolutionary tracks, then I can force an isochrone in the CMD to match the available cluster photometry by choosing a particular form of the $R - I - T_{\text{eff}}$ relation. The only other parameters involved here are cluster distance and reddening and the empirical BCs – none of which are uncertain enough to affect my conclusions. If I further assume that this $R - I - T_{\text{eff}}$ relation applies to younger stars, in IC 2391 for example, then the isochrone defined by their LDB age should coincide with the observed cluster CMD. If it does not then there is either something wrong with the evolution models or the assumption that a single colour- T_{eff} relation holds over a range of gravity is flawed. Figure 1b shows the result of doing this, assuming a Pleiades distance modulus of 5.6. There is clearly a discrepancy. Using the Hipparcos distance modulus of 5.3 makes the Pleiades LDB age older by $\sim 25\text{ Myr}$ and merely increases the discrepancy. I conclude that there may yet be a systematic problem in the evolutionary models (all of them) that could be solved if IC 2391 were younger than suggested by its LDB age. An age-dependent colour- T_{eff} relation seems less likely as it is not predicted in currently published models and spectroscopic indices in the R and I bands give reliable estimates of $R - I$ colours in all these clusters. This suggests that any gravity dependence of spectral features is heavily subordinate to the dominant T_{eff} dependence.

Table 1. LDB ages for open clusters

Cluster	Age (Myr)	Random Error (Myr)	Systematic Error (Myr)
Pleiades	122	± 18	± 11
Alpha Per	85	± 11	± 8
IC 2391	48	± 5	± 3

3.2. Age Estimates from Isochrone Fitting (DMT)

There are new efforts underway to compare the MSF and Hipparcos distances for more clusters. For example, Pinsonneault et al. (2000) have expanded their

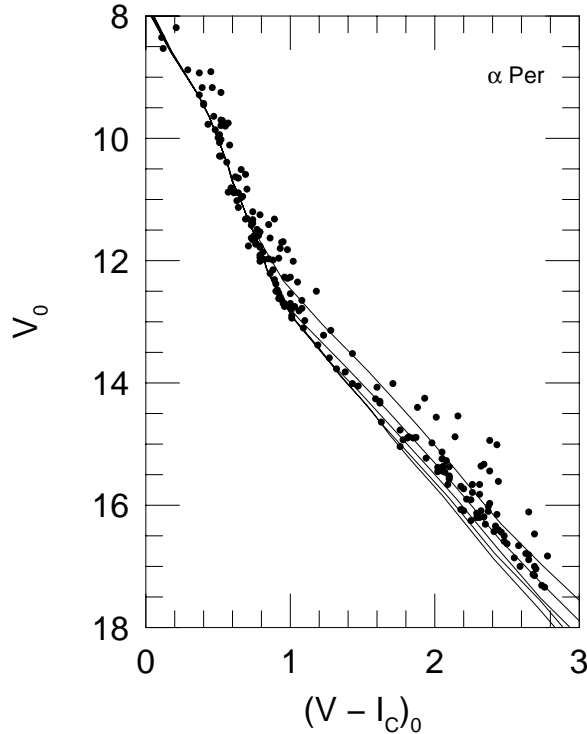


Figure 2. Color-magnitude diagram for the Alpha Persei cluster compared to isochrones of various ages. The photometry has been dereddened and the isochrones are for a distance modulus of $m - M = 6.25$. Ages are 40, 60, 80, 10, and 120 Myr; the youngest ages are brightest.

MSF technique, which employs the Yale YREC isochrones, to work over a wider range of luminosity on the main sequence than previously, by recomputing color-effective temperature transformations to reproduce the morphology of the Pleiades main sequence. For clusters younger than the age of the Hyades, the technique can be used to estimate the age of the cluster, since the lowest-mass stars are still descending towards the main sequence. This technique is illustrated in Figure 3.2., which shows a color-magnitude diagram for Alpha Per compared to isochrones of various ages. An age of 60 ± 6 Myr results. This method also generates a metallicity estimate for each cluster by comparing the distance derived using $B - V$ photometry to that obtained in $V - I$; since the luminosity depends on metallicity differently in the two colors, one derives distances which disagree unless the metallicity is correct.

Pinsonneault et al. (2000) derive distances and photometric metallicities for Alpha Per, the Pleiades, NGC 2516, NGC 6475, and NGC 6633; for other clusters they adopt the high-resolution spectroscopic abundances of Boesgaard & Friel (1992) and the distances computed in Pinsonneault et al. (1998). There are some systems (the Pleiades and Coma Ber) which still have large differences between the MSF and Hipparcos distances, while there are others (NGC 6475

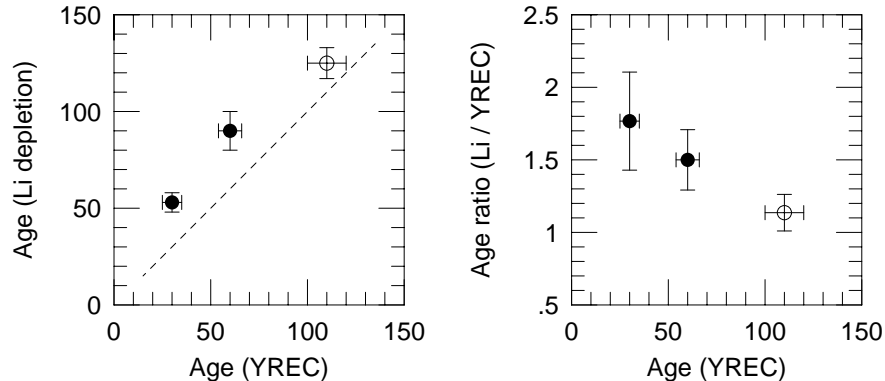


Figure 3. (a) Direct comparison of ages derived from the LDB method to ages derived from isochrone fitting to the YREC theoretical models. (b) Ratio of the LDB age to the YREC age, as a function of age.

and Alpha Per) which may possibly be in conflict depending on the treatment of the Hipparcos errors. There is no obvious pattern to the deviations with age or metal abundance, and furthermore the differences are not consistent with a simple scale shift to systematically shorter or longer distances.

In most cases, the ages derived in Pinsonneault et al. (2000) are somewhat higher than had been found from the main-sequence turnoff (as in Mermilliod 1981), but are still rather younger than the ages inferred from the LDB method. The two ages are compared in Figure 3.2. for three open clusters (from youngest to oldest being Alpha Per, IC 2391, and the Pleiades). The upper panel compares the ages directly, with the dashed line indicating equality. The ratio of the two ages is shown in the lower panel; there is probably an age-dependent offset in the two scales.

4. Cluster and Star-Forming Region Mass Functions

It is only within the past few years that open cluster mass functions that extend to low masses ($\sim 0.1\text{--}0.2 M_{\odot}$) and that are based on proper motions have started to become available. This situation has resulted from a lack of the appropriate raw materials (deep, 1st and 2nd epoch imaging data) and a lack of sufficiently good and automated measuring machines (cf. Hambly 1998). Much of the literature for open clusters in fact has not been directed at determining a mass function, but instead has concentrated on the more directly determined luminosity function. At least up until 1980, and possibly up until much later, the most cited primary reference for open cluster luminosity functions was the work by van den Bergh & Sher (1960). Those authors estimated luminosity functions for a large number of open clusters using photographic plates and estimated cluster-member data derived from counting the number of stars in annuli

centered on the apparent cluster center. van den Bergh and Sher’s conclusion from these data was that most open clusters had falling or flat luminosity functions faintward of $M_B \sim 6$, and hence that open clusters are quite deficient in low mass stars compared to the field. This result was later used as one piece of evidence in favor of bimodal star formation – in particular in favor of the idea that low mass stars are formed in loose associations (like Taurus-Auriga) and high mass stars are formed in dense clusters. However, the observational result in fact was almost certainly wrong because the outer annuli used to derive the “field” star density was chosen at too small a radius (which preferentially affects the derived number of faint cluster members due to mass segregation).

The situation in star-forming regions was not much better until quite recently, again due to a combination of lack of the right equipment (mostly sensitive, low-noise IR detectors) and lack of the right apparatus to utilize those observations (in this case, theoretical evolutionary tracks and ways to compare them to observations for very young ages). Much progress has been made in the past few years on both fronts, with the results that it is possible to begin to have confidence in the mass functions being derived for regions like rho Oph and IC 348. It is particularly likely that the derived mass functions will be close to reality when spectra have been obtained for all or most of the low mass objects so that the estimated effective temperatures are determined better and non-members can be excluded (see especially recent papers by K. Luhman on this topic).

4.1. Open Cluster Mass Functions (RDJ)

The problem of determining cluster mass functions (MFs) can be broken down into three parts: surveying for cluster members, converting the observed luminosity function into a MF and then correcting this MF for any mass-dependent spatial dispersion of stars (mass segregation).

A survey for cluster members might ideally use proper motions, photometry, radial velocities, spectral types, the presence of Li, X-ray emission or some subset of these to form an opinion on individual membership. It is clearly of vital importance to understand both the *completeness* (to include members) and *specificity* (to exclude non-members) of any membership tests. These need not be known on an individual basis, but must at least be known statistically as a function of luminosity (e.g., Hambly et al. 1999).

The conversion from luminosity functions to a MF is not trivial, relying on the age and distance of the clusters (with age becoming more important in younger clusters), a choice of stellar evolution models and a knowledge of the fraction of stars that are unresolved binary systems (with consequently larger luminosities).

The final step of correcting for the effects of mass segregation is often forgotten. For instance, the Pleiades should be almost dynamically relaxed and equipartition will have ensured that lower mass stars have a larger core radius ($r_c \propto M^{-1/2}$). This effect has been detected by Pinfield et al. (1998) and could have a large effect on the low mass end of the mass function. Unfortunately, the relaxation time also becomes longer at lower masses and this combined with the relatively low number of brown dwarfs uncovered in the Pleiades makes normalization of the brown dwarf MF in the Pleiades uncertain by a factor of ~ 2

relative to the higher mass stars (Hodgkin & Jameson 2000). Finally, there is of course the possibility of preferential ejection of lower mass cluster members that stray beyond the tidal radius. There is no alternative to a theoretical correction for this effect if one wishes to estimate the *initial* MF from a present-day MF. Clearly these dynamical effects have considerably less influence in younger clusters and associations.

The state of the art MF for open clusters is that derived in the Pleiades (Bouvier et al. 1998, Hambly et al. 1999, Hodgkin & Jameson 2000). This now extends from the A stars down to brown dwarfs at $\simeq 0.04M_{\odot}$. Whilst there is still disagreement on the exact representation of the MF, a number of clear points have emerged. (i) The MF cannot be represented as a single power law, but a log-normal MF, similar to that proposed by Miller & Scalo (1979) certainly does a reasonable job down to $0.08M_{\odot}$. (ii) A power law fit to the brown dwarf MF still has uncertainties of 50% or so in the power law index because of the uncertainties in membership, small number statistics and uncertain dynamical effects. However, if the cluster MF is similar to the field MF, it is clear that brown dwarfs ($0.04 < M < 0.08M_{\odot}$) contribute negligibly to the Galactic disk mass. (iii) There is no evidence for a steep turnover or truncation of the MF down to $0.04M_{\odot}$.

4.2. Comments on the Mass Function of the Pleiades (ELM)

My collaborators and I have obtained new IR photometry and optical spectroscopy of all of the very low mass and brown dwarf candidate members of the Pleiades proposed in Bouvier et al. (1998). We have used those new data (Martín et al. 2000) to attempt to determine which of these stars are real members of the cluster, and which are instead field star contaminants. The criteria used include spectral type and luminosity class, presence and strength of H α emission, and location in color-magnitude diagrams. In addition, we consider other published information such as the presence of lithium in absorption and radial velocity.

Table 2 provides a summary of the membership information for these stars. The bottom line is that the success rate for the Bouvier et al. candidate list is in the range 63% to 78%, depending on the status of the YES? stars (for which the results are currently not definitive). Bouvier et al. had predicted a probable success rate of 75% based on a simple field star luminosity function and survey volume argument. The new data are consistent with the original estimate, with a possibility of somewhat more field star contamination than expected. Therefore, the Bouvier et al. estimate of the Pleiades IMF down to $0.04 M_{\odot}$ is supported by the new membership study, indicating a slightly rising mass function below the hydrogen burning mass limit. This mass function is slightly less steep than the mass function derived by Martín et al. (1997), based on the IAC Pleiades surveys which concentrated on fields somewhat closer to the cluster center than the CFHT fields. This could be a hint that the brown dwarfs are more concentrated to the cluster center than the VLM stars.

Table 2. Membership Assessment in the Pleiades

Name	Other Name	Dwarf?	V_{rad}	pm	Li	H α	Spec. type	I vs. $I - K$	NIC Seq	Member?
CFHT 1		Yes				Yes	Yes	Yes		Yes
CFHT 2		Yes				Yes	Yes	Yes		Yes
CFHT 3*	HHJ 22	Yes		Yes				Yes		Yes
CFHT 4								Yes		Yes?
CFHT 5		Yes				Yes	Yes	Yes		Yes
CFHT 6		Yes				No	Yes	Yes		Yes?
CFHT 7		Yes				No	Yes	Yes		Yes?
CFHT 8		Yes				Yes	Yes	Yes		Yes
CFHT 9		Yes			No	Yes		Yes		Yes
CFHT 10		Yes			No	Yes		Yes		Yes
CFHT 11	Roque 16	Yes			Yes	Yes		Yes	Yes	Yes
CFHT 12		Yes			Yes	Yes		Yes	Yes	Yes
CFHT 13	Teide 2	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes
CFHT 14		Yes			No	No				No
CFHT 15		Yes			Yes	Yes		Yes	Yes	Yes
CFHT 16		Yes					No	Yes?	Yes?	Yes?
CFHT 17		Yes				Yes	Yes	Yes	Yes	Yes
CFHT 18		Yes			No	Yes	Yes	Yes	No	No
CFHT 19		Yes				Yes	Yes	No	Yes	No
CFHT 20		Yes				No	Yes	No	No	No
CFHT 21	Calar 3	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes
CFHT 22		Yes					Yes	No	No	No
CFHT 23		Yes						Yes	Yes	Yes
CFHT 24	Roque 7	Yes					Yes		Yes	Yes
CFHT 24.1	PÍZ 1	Yes					Yes	Yes	Yes	Yes
CFHT 25		Yes				No	Yes	Yes	Yes	Yes
CFHT 26		Yes				No	No			No
KPNO 3*	HHJ 20	Yes		Yes				Yes		Yes
KPNO 4*	HHJ 28	Yes		Yes				Yes		Yes
KPNO 5										Yes?

*Dwarf status inferred from proper motion.

References

- Barrado y Navascués, D., Stauffer, J. R., & Patten, B. M. 1999, *ApJ*, 522, L53
- Basri, G., Marcy, G., & Graham, J. 1996, *ApJ*, 458, 600 (BMG)
- Basri, G., & Martín, E. L. 1999a, *AJ*, 118, 2460
- Basri, G., & Martín, E. L. 1999b, *ApJ*, 510, 266
- Becker, W., & Fenkart, R. 1971, *A&AS*, 4, 241.
- Bildsten, L., Brown, E., Matzner, C., & Ushomirsky, G. 1997, *ApJ*, 482, 442
- Boesgaard, A. M., & Friel, E. D. 1990, *ApJ*, 351, 467
- Bouvier, J., et al. 1998, *A&A*, 336, 490
- Burrows, A., et al. 1997, *ApJ*, 491, 856
- Chabrier, G., & Baraffe, I. 1997, *A&A*, 327, 1039
- D’Antona, F., & Mazzitelli, I. 1997, *MSAI*, 68, 807
- Hambly, N. C. 1998, in *ASP Conf. Ser. 134, Brown Dwarfs and Extrasolar Planets Proceedings*, ed. R. Rebolo, E. L. Martín, M. R. Zapatero-Osorio (San Francisco: ASP), 11
- Hambly, N. C., Hodgkin, S. T., Crossburn, M. R., & Jameson, R. F. 1999, *MNRAS*, 303, 835
- Hodgkin, S. T., & Jameson, R. F. 2000, in *Stellar clusters and associations: Convection, rotation and dynamos*, ed. R. Pallavicini, ASP Conference series, in press
- Lindgren, L. 1988, in *Scientific Aspects of the Input Catalog Preparation II*, January 1988, ed. J. Torra, & C. Turon (Noordwijk: ESA), 179
- Lynga, G. 1987, *Catalog of Open Cluster Data* (5th Edition, Lund: Lund Observatory)
- Martín, E. L., Zapatero Osorio, M. R., Rebolo, R. 1997, in *ASP Conf. Ser. 134, Brown Dwarfs and Extrasolar Planets Proceedings*, ed. R. Rebolo, E. L. Martín, M. R. Zapatero-Osorio (San Francisco: ASP), 507
- Martin, E. L.; Basri, G.; Gallegos, J. E.; Rebolo, R.; Zapatero-Osorio, M. R.; Bejar, V. J. S. 1998, *ApJ*, 499, 61
- Mazzei, P., & Pigatto, L. 1988, *A&A*, 193, 148
- Mermilliod, J.-C. 1981, *A&A*, 97, 235
- Meynet, G., Mermilliod, J.-C., & Maeder, A. 1993, *A&AS*, 98, 477
- Miller, G. E., & Scalo, J. M. 1979, *ApJS*, 41, 513
- Narayanan, V. K., & Gould, A. 1999a, *ApJ*, 515, 256
- Narayanan, V. K., & Gould, A. 1999b, *ApJ*, 523, 328
- Perryman, M. A. C., et al. 1998, *A&A*, 331, 81
- Pinfield, D., Jameson, R. F., & Hodgkin, S. T. 1998, *MNRAS*, 299, 955
- Pinsonneault, M. H., Stauffer, J., Soderblom, D. R., King, J. R., & Hanson, R. B. 1998, *ApJ*, 504, 170
- Pinsonneault, M. H., Terndrup, D. M., & Yuan, Y. 2000, in *Stellar Clusters and Associations: Convection, Rotation, and Dynamos*, ed. R. Pallavicini, ASP Conf. Ser., in press

- Rebolo, R., Martín, E. L., Basri, G., Marcy, G. & Zapatero-Osorio, M. R. 1996, ApJ, 469, L53
- Robichon, N., Arenou, F., Mermilliod, J.-C., & Turon, C. 1999, A&A, 345, 471
- Soderblom, D. R., King, J. R., Hanson, R. B., Jones, B. F., Fischer, D., Stauffer, J. R., & Pinsonneault, M. H. 1998, ApJ, 504, 192
- Stauffer, J. 1984, ApJ, 280, 189
- Stauffer, J., et al. 1989, ApJ, 346, 160
- Stauffer, J. R., Schultz, G., & Kirkpatrick, J. D. 1998, ApJ, 499, L199 (SSK)
- Stauffer, J. R. et al. 1999, ApJ, 527, 219
- Ushomirsky, G., Matzner, C., Brown, E., Bildsten, L., Hilliard, V., & Schroeder, P. 1998, ApJ, 497, 253
- van den Bergh, S., & Sher, D. 1960, Pub. DDO, 2, 203
- van Leeuwen, F. 1999, A&A, 341, L71
- Ventura, P., Zeppieri, A., Mazzitelli, I., & D'Antona, F. 1998, A&A, 334, 953